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Renewable energy policies for sustainable development in Cambodia

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ABSTRACT

In line with sustainable development path, electrification with the aid of renewable energy resources is a key element for the developing countries. Cambodia with almost 85% rural population is one of the countries with high renewable energy resources but at the same time has a low installed capacity. In the context of this study, the potential and status of sustainable energy generation in Cambodia are studied in detail. The renewable energy policies, strategies and programs are investigated, and the implemented projects based on the determined policies are reviewed. Considering the existing governmental policy of enabling 70% of rural households to reach reliable electricity services by 2030, the renewable energy resources are found as the best option for rural electrification. The economic, regulatory, financial and institutional barriers are shown as the main cause of the significant deviation between the potential and installed capacity. It is essential to overcome the challenges in order to achieve a sustainable development in rural electrification in Cambodia.

Contents

1. Introduction

Cambodia with the population of around 15 million is located in Southeast Asia with two main seasons. The wet season from May to October and dry season from October to April can be considered as the main seasons in Cambodia [1]. Around 85% of population are living in rural areas and their primary livelihood is agriculture [2,3]. Based on the world bank report, the GDP per capita in Cambodia is reported to be around USD874 in the year 2011 [4], which placed the country as the 16th lowest income country in the world [5]. Although the conventional energy resources of Cambodia are considerable such as fuel wood, coal, forestry, fossil fuel, petroleum, oil and natural gas reserve [6–9],

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these energy resources are limited. In order to cover the energy demand, it is essential to use other energy resources that are cheaper and sustainable, like renewable energy resource.

Towards development and augmentation of electricity generation previous studies focused on renewable energy potential to employ these energies in a feasible way and also to utilize technical methods for conservation of energy. In the context of the present study the renewable energy policies, strategies and programs in Cambodia are investigated and the implemented projects based on the determined policies are reviewed.

2. General consideration of energy resources in Cambodia

2.1. Conventional energy resources

Among the various natural energy resources in Cambodia, diesel and heavy fuel oil are mostly used to produce the needed electricity of the country. Fuel wood, which is exploited from the natural forest, is one of the natural energy sources in Cambodia. More than 80% of the population depend on agricultural activity for their livelihood; thus the usage of wood and agricultural residues as the energy sources is significant. The average required fuel wood for one family is 5.27 t/year in Kampong Chhnang province.

There is no clear data to evaluate the amount of fossil fuel in Cambodia [7,10,11]. Estimation of oil and natural gas's amount is possible with test drills in the part of Cambodia's offshore of the Thailand's gulf. Test drills have revealed the potential existence of assumedly largest offshore natural gas fields. Since Thailand has confirmed gas deposits and has been commercially exploiting them, the probability is high that Cambodia will in the long term be able to undertake similar exploration [7]. According to the ASEAN reports, natural gas reserve is estimated to be around 9.9 trillion cubic feet [6].

Coal deposit can be exploited from several provinces. The use of charcoal rapidly increased to 40% in 2010 but will steadily decline to 30% from 2013 to 2030. Liquefied petroleum gas (LPG) is another conventional source that is mainly used by a higher social class. LPG is hardly used at the moment but the usage is expected to be increased to 50% of the energy mix in 2030. LPG is going to replace charcoal and wood in the future; however due to its limited resources, in long term it would be better that this is replaced by renewable energy sources [3]. Average LPG, charcoal and kerosene consumption for the two provinces of Kampong Speu and Svay Rieng are compared in Table 1.

The total required charcoal, LPG and kerosene in the rural area of Cambodia in 2020 are estimated to be 12,156 TJ, 4671 TJ and 673 TJ, respectively. The estimated rural energy demand for charcoal, LPG and kerosene in Cambodia until 2030 is shown in Table 2.

Table 1
Fossil fuel consumption in Kampong Speu and Svay Rieng province [3].

	Kampong Speu		Svay Rieng	
	Fuel consumption	Produced energy (GJ/Year)	Fuel consumption	Produced energy (GJ/Year)
LPG (kg/month)	25.52	115,813	13.51	24,680
Charcoal (kg/month)	110.4	449,509	33.3	30,167
Kerosene (liters/month)	5.78	80,486	5.59	60,951

Table 2
Estimated rural energy demand in Cambodia (TJ) [3].

	2007	2010	2012	2015	2017	2020	2022	2025	2027	2030
Total charcoal	5107	6796	8532	12,323	12,441	12,156	12,153	11,998	12,137	13,112
Total LPG	1885	2313	2512	3135	3591	4671	5570	7020	7763	8964
Total kerosene	1108	1166	978	843	735	673	674	731	767	717

2.2. Renewable energy resources

Since there is no official and comprehensive investigation of Cambodia's renewable energy resources, achieving sustainable energy development, in which a fair distribution of renewable sources is meeting, is impossible. The estimated potential renewable sources and the installed projects in 2004 are summarized in Table 3. Comparing the technical potential of the renewable energy resources and the installed projects in Cambodia, it can be found that there is still a large amount of available renewable energies that can be utilized for electricity generation.

It is also estimated that renewable energy sources of Cambodia can generate potentially 67,388 GWh energy per annum. This energy is almost three times of the total energy consumed by the whole economy. It can be seen that the largest potential for electricity generation is estimated to belong to hydropower [12].

2.2.1. Hydropower resources

Cambodia has enormous water resources for hydropower development and in some parts of the country mini/micro/Pico hydropower can provide opportunities for rural electrification. Cambodian political governments also have expressed strong support for large-scale hydropower projects, citing the need to secure access to cheap electricity to supply the expanding economy. In 1999, the technical potential of hydropower resources is estimated to be 8000 MW by Greater Mekong Sub-region (GMS) [13] and 8600 MW by Asian Development Bank [6]. Ministry of Industry, Mines and Energy and ASEAN countries reported a 10,000 MW capacity of large-scale and 300 MW in mini/micro/Pico scale [14]. 15,000 MW technical potentials of hydropower are addressed by the JICA Master Plan study in Cambodia. About half of the mentioned resources are based in the Mekong River Basin and 40% of these are located in the

Table 3
Estimated potential and status of sustainable energy generation [7].

	Technical potential (GWh/year)	Currently installed projects (GWh/year)	Potential annual greenhouse gas abatement (k ton CO_2 eq.)
Hydropower	37,668	55	26,228
Biomass	18,852	0	13,146
Solar	65	1	44
Wind	3665	0	2556
Industrial energy	547	0	381
Residential energy	6591	29	4576
Total	67,388	85	46,931

branches of the Mekong River and rest (about 10%) are in the southwestern coastal areas [12]. Although the reported potential capacity of hydropower in Cambodia is significant, the utilization of hydropower resources was only about 145 MW in 2000 [6] and 20 MW in large-scale and 1 MW in mini/micro/Pico scale [14].

2.2.2. Biomass energy

Biomass energy includes agricultural residues, fuel wood, animal wastes, municipal wastes and other fuels derived from biological sources. One of the common applications of solid biomass is in direct combustion steam turbine that needs more than 1 MW. The available types of biomass resources in Cambodia are categorized into agricultural residues that include rice husks and other agricultural residues, woody biomass that comprise old rubber trees (Hevea brasiliensis), natural forest and forest plantations [15]. Some selected biomasses in Cambodia and their higher heating value (HHV) are summarized in Table 4. It is estimated that the wood energy demand will increase from 73,637 TJ in 2007 to 35,522 TJ in 2030 and the total animal dung usage also predicted to vary from 683 TJ to 1068 TJ in this period [3,16,17].

2.2.3. Solar energy

Cambodia receives a relatively high level of solar radiation throughout the year; on average sunlight is available for 6.8 h per day and consequently 2490 h per year. Starting to increase from January, the solar radiation in Cambodia reaches a maximum value in March and April. A value of 18.3 MJ/m^2-day is also reported for the average global irradiation throughout the whole area of Cambodia [18]. The average Cambodia sunshine hour is shown in Table 5.

The solar PV technology has been used for lighting, radio, TV and telecommunication in the rural areas since 1997 in Cambodia. Based on the new energy and industrial technology development organization that used a 10-year annual average solar irradiation of 5.10 kWh/m^2 per day and considering 0.02% of Cambodia's land area is suitable for installing PV modules, the preliminary solar power generation potential is estimated to be around 21 GWh/day. The solar hot water potential is estimated to be 49.3 GWh per day. In comparison with the potential solar energy resources, the current utilization of solar power in the country is low. The total installed capacity was 205 kW in 2002 and was increased to over 300 kW by the beginning of 2004 [12] and it was predicted to reach 700 kW in 2005 based on the ASEAN report [14]. Although to the best of the authors' knowledge, the solar generated electricity in Cambodia is only limited to a hybrid system composed of a PV unit with 50 kW capacity and two biomass gas digestions each producing 35 kW. This shows that a great solar potential is still unutilized and there is an extensive room for more work and research. One of the next goals is to install 12,000 solar home systems (SHS) throughout seven provinces from mid-2011. The main obstacles to the advancement of industry in Cambodia are accessibility, awareness and affordability [12].

2.2.4. Wind energy

The total wind energy potential in Cambodia based on Atlas Report in Southeast Asia that covers Cambodia, Thailand and Vietnam is reported to be around 1380 MW. The detailed potential capacities based on the wind characteristics are presented in Table 6.

However, the southern coastal area (Sihanouk Ville, Kampot, Kep, Koh Kong) and mountainous areas in the southwest and northeast of the country, as well as on the southern part of the great lake Tonle Sap, have favorable wind condition with average speed of 5–7 m/s. So after the installation of a 400 W wind generator in these areas for half of rural households, the ultimate total capacity would approximately become equal to 22 MW resulting in a 39 GWh generation per year. Wind energy is subjected to great seasonal variations, besides the electricity generation application, wind energy has been utilized for water pumping in the central part of Cambodia as well (Prey Veng province) which is supported by a non-governmental organizations (NGO) with installed capacity of 700 kW [12,14,21].

3. Power generation and power consumption

Based on the electricity authority of Cambodia, the percentage of households who had access to the electricity in 2008 were reported to be 16.41% and around 73% of them are located in Phnom Penh area [22–24]. The total expected generation output for Cambodia is estimated to be 2640.7 GWh in 2016 and the generation for different cities of Cambodia is plotted in Fig. 1.

In meeting the growing demands of electricity, different strategies can be addressed. Among them, the National Transmission System Development Plan and Power Generation Development Plan are the two prime examples. The plans are summarized in Tables 7 and 8.

Table 5
Cambodia sunshine averages (hr) [19].

Month	Sunshine hour	Month	Sunshine hour
January	8.4	July	4.6
February	8	August	5.6
March	8.6	September	4.3
April	8	October	6.5
May	6.5	November	7.1
June	6.4	December	7.8

Table 4
HHV of selected biomass in Cambodia [15].

Sample name	HHV (MJ/kg)	Sample name	HHV (MJ/kg)
Agricultural residues		**Woody biomass**	
Cashew nut shell	23.62	Eucalyptus camaldulensis	20.1
Bagasse	15.68–19.50	Acacia auriculiformis	20
Corn cob	17.72	Leucaena leucocephala	19.53
Rice husk	15.38	Casuarina Sp.	19.27
Peanut shell	18.92	Memecylon acuminatum	19.14
Coconut shell	18.56	Hevea brasiliensis (rubber)	18.89
Cassava stem	18.59	Gliricidia sepium	18.38
Mulberry (Morus Alba) stems	18.33	Morus Alba (mulberry)	18.33
		Cassia Sp.	17.95

Table 6
Wind energy potential in Cambodia [20].

Wind characteristics	Poor (< 4 m/s)	Fair (4–5 m/s)	Good (5–6 m/s)	Very good (6–7 m/s)	Excellent (> 7 m/s)
Percentage of total land area (%)	96.4	3.4	0.2	0	0
Potential capacity (MW)	NA	24,620	1260	120	0
Proportion of rural population in each small wind turbine resource class	15%	79%	5%	1%	0

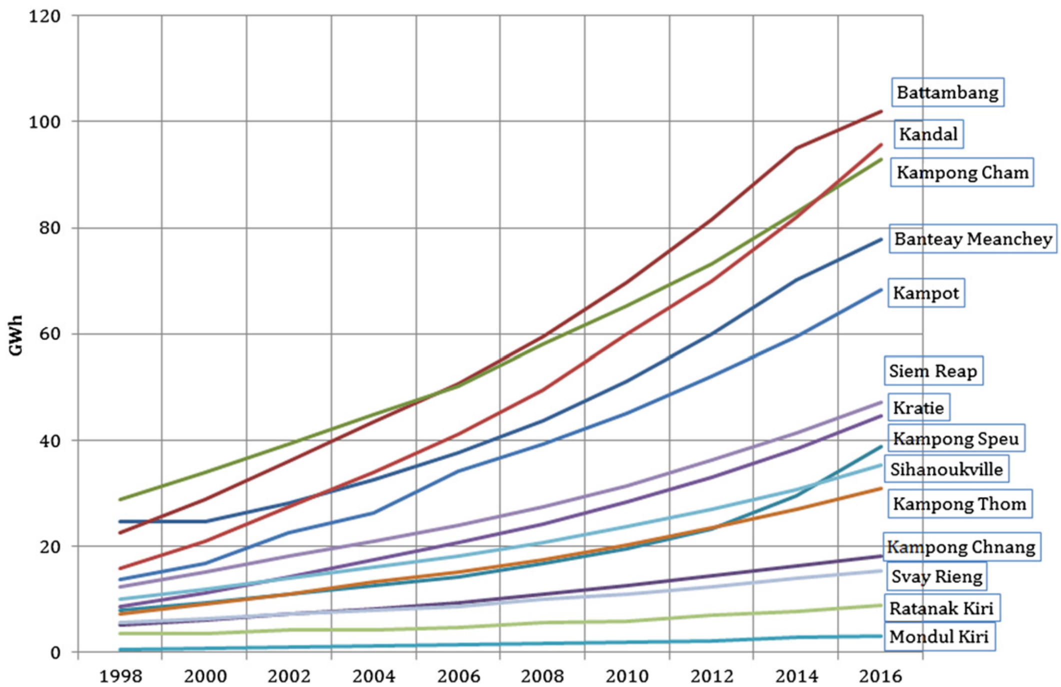

Fig. 1. Expected generation output for Cambodia (GWh)—base case [22,23].

Table 7
Power generation development plan [20,25].

Stage 1	
2004	10 MW HFO power plant in Siem Reap (Japanese Grant). Power supply in 8 provincial towns.
2005	32 MW HFO (IPP—Khmer Electric).
2006	10 MW HFO (Japanese grant).
2007	Power import: 80 MW from Vietnam; 20 MW Thailand.
Stage 2	
2009	Kirirum III 13 MW hydropower plant (IPP-CETIC). Power import extension from Vietnam 200 MW.
2012	Battambang 1,2&3 hydropower plants 73 MW.
2013	300 MW thermal plant in coastal line area.
Stage 3	
2014	180 MW Kamchay hydropower plant.
2015	125 MW Russey Chrum hydropower plant.
2016	110 MW Stung Atay hydropower plant.
2018	465 MW Sambor hydropower plant.
2020	207 MW Lower Se San 2 hydropower 222 MW Lower Srepok hydropower
After 2020	980 MW Stung Treng hydropower plant 260 MW Stung Chay Areng hydropower plant

4. Energy policies

Limited financing, inadequate policies and weak institutional frameworks are the main problems that have encompassed rural electrification in most developing countries. Therefore, governments have made various attempts in financing and facilitating the increase in the level of rural electrification in the last two decades [26]. Generally, several encouraging steps have been taken towards greater liberalization in developing renewable energy. The most important priority is providing domestic energy resources, which can happen through a mix of private, public and foreign capital in the medium and long time scales. Basically, the government should make some opportunities for the private sector that associated with energy, for investment in the power industry and to pace the capacity extension. By upgrading the power transmission as well as distributing grid, the reliability of electricity supply can be improved that will result in enhancing the public health and environmental conditions [27–29].

In 2007, the rural electrification by Renewable Energy policy was integrated to the government's overall agenda for the energy sector. Providing reliable, affordable and adequate supply of electric power for the consumers can be pointed out as the prime focus of this national policy. Moreover, promoting private ownership of electrical facilities and encouraging competition among the involved companies in the energy sector are the other objectives that are followed based on this policy [20].

Enabling 70% of rural households to reach reliable electricity services by 2030 is one of the long-term determined targets by Royal Government of Cambodia (RGC). The government focuses on providing energy services and improving the quality of life for the rural population in their two main policies: Energy Sector Development Policy and Rural Electrification Policy. Development of renewable energies is one of the approaches that are adopted to meet the mentioned objective. Rural electrification fund (REF) subsidy and investment incentives are two main policy instruments that support the Energy Sector Development and Rural Electrification Policies financially. Based on the REF documents among the renewable technologies the SHSs and mini/micro

Table 8
National Transmission System Development Plan [20].

Stage 1	
2007	115 kV single line interconnection from Thailand to Banteay Meanchay, Battambang and Siem Reap
	220 kV double circuit interconnection from Vietnam to Phnom Penh substation
	220/115/22 kV (WPP) including substation 115/22 kV at East Phnom Penh (EPP)
	Establishment of 115/22 kV terminal substation at Phnom Penh (NPP) and stringing a second a 115 kV transmission circuit between GS1 and NPP
Stage 2	
2008	Establishment of Takeo to Kampot 230 kV transmission line including substation 230/22 kV in Kampot, Germany grant aid
2009	120 km single circuit 230 kV transmission line from Phnom Penh (WPP) to Kampong Cham including a substation 115/22 kV at Kampong Cham
2010	Transmission line 260 km double circuit 230 kV between Phnom Penh (WPP) and Battambang via Kampong Chhnang and Pursat including substations in Kampong Chhnang and Pursat
2011	Transmission line 230 kV from Sihanoukville to Phnom Penh (WPP) along National road 4
2012	122 km single circuit 115 kV transmission line from Phnom Penh to Svay Rieng via Neak Loeung including terminal substations at Neak Loeung and Svay Rieng
2013	Transmission line 230 kV From Kampot to Sihanoukville
Stage 3	
2016	Double circuit 230 kV transmission line linking Stung Atay hydropower plant to Pursat substation.
2018	Connection of 230 kV line from Kampong Cham substation to Sambor hydropower plant, Transmission line 230 kV linking Kampong Cham to Siem Reap via Kompong Thom,
2020	Transmission line 500 kV linking Sambor, Stung Treng, Lower Se San 2 and Lower Srepok 2 and connect to the ASEAN grid (power exchange between Cambodia-VietNam, Thailand and Laos).

Table 9
The electricity generation policies and programs in Cambodia [23,31,33].

Name of Policy/program	Main objectives	Target year
Electricity Sector Development Policy	Development of generation and transmission.	1994–2014
Master Plan study Rural electrification by renewable energy in the kingdom of Cambodia	Off-grid electrification with micro hydropower scheme.	2006
Rural Energy Strategy Program	Rural electrification	2011–2015
	Non-power rural energy	2016–2020
		2021–2030
Renewable energy program	15% of electricity generation with renewable energy.	By 2015
Rural Electrification Plan	90% of villages have access to electricity in different form.	By 2020
Rural Electrification Plan	Electrification of 70% of rural households.	By 2030

hydropower are the ones who are qualified for subsidies scheme [30–33]. In order to reach the long-term goal, a 10-year target was developed as the medium term to connect 25% of households to the electrical service. The formulated electrification policies and programs are summarized in Table 9.

It can be clearly observed that the development of electricity generation and transmission was taken into account from 1994 by electricity sector development policy. The electrification trend was followed by several policies with the main objective of rural electrification. Some of the determined targets by the electrification policies and programs are short-term goals as the one in the master plan or in the initial stage of the rural energy strategy program, whilst in other programs (rural electrification plan) the long-term goals are taken into account.

5. Institutions

The main renewable energy institution is associated with the Royal Government of Cambodia and it is divided into three institutions of electricity of Cambodia (EAC), ministry of industries, mines and energy (MIME) and ministry of economic and finance (MEF). Among them, MIME is in charge of the energy issues in Cambodia. Generally, it develops energy policies, strategic plans and standards (technical, safety, and environment). Cambodia's electricity market is divided into four institutes (IPP, PEU, EDC and REE) and the rural electrification funds allocated to mini and micro hydro projects and solar home system are given to these institutions [34]. There are numerous international and local institutions that are working in different energy areas and electricity generation that are summarized in Table 10.

6. Implemented projects

Considering the potential capacity of hydropower, the current utilization of this natural source is relatively low. Based on the JICA Master Plan Progress report in 2005, capacity of the two installed hydropower projects is reported as 13 MW that includes 12 MW in Kampong Speu and 1 MW in Ratanak Kiri. The first mentioned project was implemented in 2002 and the second one was started in 1993. A 200 kW hydropower project in Mondul Kiri and the Kamchay HEPP with the capacity of 180 MW are under implementation and planning. Katieng Micro Hydro is under development by UNIDO with approximately 1076 kW capacity.

Having a look on the biomass based projects, it can be pointed out that the wood fired and rice husk gasifiers are used to power a small grid operated by a village community with the capacity of 10–200 kW. The cogeneration process of different biomasses is taken into account by the implemented electrification projects in rural areas. The prime examples are 1.5 MW rice husk cogeneration developed by COGEN3 program and a 500 kW cashew nut-fired cogeneration.

A hybrid system, which is composed of biogas generation of 70 kW capacity and 50 kW PV system, was founded for electrification in Prey Nop, Sihanouk Ville. The biogas generation system without a storage power battery integrated with a solar system has been created to make up for the variations occurring in the power generated by the solar system due to weather conditions as well as insulation, by using a supplement of an inverter and a secondary machine for which a variable rotational frequency is provided with the aid of a biogas generation system. This stabilized generated power is then transferred from Constant Voltage Constant Frequency System (CVCF) by interconnecting

Table 10
Institutions in different energy areas and electricity generation.

Institute	Working area
Department of Energy Development	Energy sector planning and consumption and data collection [35]
Electricity Authority of Cambodia (EAC)	Licensing, tariff setting, solving the disputes between producers/suppliers and consumers, setting up the uniform accounting standards, enforcing the regulation, reviewing of planning and financing performance [36,37].
Electricity du Caboodle (EdC)	Responsible for the utility generation, transmission and distribution of power in nine areas of the country (provincial towns and Phnom Penh), selling 90% of the electricity used in Cambodia [13]
Rural Electricity Enterprises (REEs)	Working on areas that are not covered by EdC (4 Provincial towns and hundreds of smaller towns and village), generating and distributing electricity [38]
United Nations Development Program Cambodia (UNDP)	Strengthening national and local capacities in environmental and natural resources management, climate change and ozone depletion [39,40].
New Energy and Industrial Technology Development Organization, Japan (NEDO)	Rural electrification: A hybrid system of PV (80 kW) and Micro Hydro (40 kW) in Kampong Cham Province, Hybrid PV (50 kW) and Biogas (60 kW) in Sihanoukville [37,41]
National Biodigester Program (NBP)	Biogas, bio-digesters, decreasing the CO_2 emission, under supervision MAFF [42]
Canadian companies with Department of Alternative Energy Development and Efficiency (DEDE)	Biomass Gasification Project in Battambang (7 kW–20 kW) [26]
Thailand company	30 kW in Kompong Cham [26]
FONDEM France	30 kW in Sambour District, Kompong Thom Province in 2009 [26]
Vietnamese (EVNI) and Chinese companies	Rural electrification: Hydro [43]

Table 11
Result of using biogas technology.

Technical features	Amount
Chemical fertilizer reduction/year	50 kg per household
Total CO_2 emission reduction saved/year	4.74 t CO_2 eq.
Fuel wood saved/year	2.210 kg per household
Kerosene savings/year	28.8 l per household

Table 12
Challenges of renewable energies and electrification development.

Economic	Access issues, lack of pricing policies, financing concerns
Legal and regulatory	Short leash syndrome, lack of static data, institutional structure, policy and regulatory framework, monitoring and evaluation framework
Financial and institution	Institutional structure, access issues

the biogas generation section. In addition, biogas generation and fermentation plants with corresponding facilities are outlined and the operation results are also demonstrated [44]. Some of the advantages of biogas technical features with amount are shown in Table 11.

7. Challenges of renewable energies and electrification development

The common issues in electrification development with the renewable energies can be considered in one of the three main categories of (I) economic, (II) legal and regulatory and (III) financial and institutional. The existent barriers facing the renewable energy development in Cambodia are listed in Table 12 based on the determined classification.

Lack of static data on electricity consumers and suppliers and business cost for project development, operation and maintenance create barriers to develop projects. Policy makers can overcome this issue with sufficient time and money [7]. An inefficient legal environment in which the laws awaiting approval are still in the process exacerbates the weak regulatory framework in Cambodia. Lack of a clear division of the responsibilities between the energy companies and financial institutions is the result of poor policies and regulatory framework. Taking an in-depth look into the financial issues of renewable energy development, the high initial cost of renewable energy systems due to the high import tax (35%) and higher electricity price can be pointed out as the main problems of rural consumers. On the other hand, lack of favorable investment environment and loan systems for the energy provider is known to be the main issue of energy providers [45–47].

8. Conclusion

In investigating the potential capacity of renewable energy resources in electricity generation, it is found that Cambodia is one of the richest countries in natural energy resources among the developing countries. The solar, wind, biomass and hydropower energy resources are studied in the context of this study and it is estimated that renewable energy resources of Cambodia can generate up to 67,388 GWh energy per year. This energy is almost three times of the total energy consumed by the whole economy.

Since the percentage of households with reliable access to electricity were reported to be 16.41% in 2008, different policies and plans are formulated in Cambodia. Electrifying 90% of the villages and 70% of all rural households by 2020 and 2030 respectively is one of the most important formulated policies by

the Royal Government of Cambodia. All the implemented projects and allocated funds for the rural electrification projects are based on the approved energy policies. The documented policies for electrification with renewable energies involved institutions and implemented projects were investigated in this study. Finally, the common barriers and challenges that make the electrification development difficult were investigated. It is found that all the barriers can be classified into three main categories of (a) economic, (b) legal and regulatory and (c) financial and institution. Overcoming the common challenges that hinder the electrification development would result in a better electrification trend and increase the quality of Cambodian citizens.

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